# WAR DEAFNESS AND ITS PREVENTION—REPORT OF THE LABYRINTHS OF THE ANIMALS USED IN TESTING OF PREVENTIVE MEASURES. (MIDDLE EARS PREVIOUSLY REPORTED)

BY

STACY R. GUILD

From the Department of Anatomy, University of Michigan Medical School, Ann Arbor, Michigan

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# WAR DEAFNESS AND ITS PREVENTION—REPORT OF THE LABYRINTHS OF THE ANIMALS USED IN TESTING OF PREVENTIVE MEASURES.* (MIDDLE EARS PREVIOUSLY REPORTED)†

By Stacy R. Guild, Ann Arbor, Mich.

## METHODS

A FULL description of the procedure by which each animal was handled at the time of exposure to the detonations was given in the report of the middle ear conditions; reference may be made to it for that part of the technic. In that report the protective measures tested were also listed and described. As stated there the animals were killed about 48 hours after exposure to the detonations. The treatment of the tissues at the time of killing the animals was directed primarily to the securing of the best possible cochlear fixation. The method used was the one with which I had had the best results in a series of experiments on cochlear histologic technic, conducted as a preliminary to objective work on the physiology of hearing which the war has postponed indefinitely, but which I hope at some future time to carry out. The fixation fluid used was Zenker-formol in the proportions suggested by Maximow (1909), as a modification of Helly's fluid, for other work. A stock solution is made in the following proportions:

| | |
|---|---|
| Mercuric bichloride, | 50 gm. |
| Potassium dichromate, | 25 gm. |
| Sodium sulphate, | 10 gm. |
| Distilled water, | 1000 c.c. |

This was filtered carefully to exclude any particles which might block small vessels. Just before using there was added to this stock solution 10 per cent by volume of 10 per cent formalin; the glacial acetic acid of the regular Zenker's fluid was not added. Both solutions were kept in an oven at 39° C. until the time of mixing for use. The fixative was injected through the vascular system, following a thorough washing out with a 0.75 per cent solution of sodium chloride, also kept at 39° C. until placed in the flask for injection. This preliminary washing out is essential for the securing of good penetration of the fixative.

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From the Department of Anatomy, University of Michigan Medical School, Ann Arbor, Michigan.

†Three previous reports have been made; the first was published in this Journal, September, 1917; the second, January, 1918; and the third, March, 1918. The second report is the one containing the account of the middle ears the labyrinths of which are here reported.

The routine procedure was to place the animal under chloroform anesthesia; then to open the thorax and pericardial sac and insert the cannula of the injecting apparatus in the systemic aorta through the wall of the left ventricle, the ligature being placed by passing the thread through the transverse sinus of the pericardium, thus including the pulmonary aorta. This can be done very rapidly after a few trials and I was able regularly to have the saline solution running soon enough to avoid any clotting of blood in the cochlear vessels. The vessels to the caudal half of the body were routinely clamped off by a hemostat placed so as to include both aorta and inferior vena cava just above the diaphragm. This reduced the amount of fluid necessary for satisfactory injection of the cochlear region. The injection was made with air pressure averaging 145 mm. of mercury. About 150 c.c. of warm saline solution were used in washing out the blood and this was followed immediately by 200 c.c. of the warm fixative described above. Only a small portion of this reaches the cochleae, of course, since all the blood vessels of the upper half of the body are injected. The cochleae and some of the surrounding bone, including most of the vestibular parts, were then removed and the two pieces placed in 50 c.c. of warm fixing fluid and left at room temperature. These remained in the fixing fluid from a week to ten days, the fluid being changed two or three times, because a precipitate forms slowly after mixing the formalin with the Zenker stock solution. They were then washed for 24 hours in running tap water and placed in 10 per cent alcohol; and were transferred from this to 80 per cent alcohol by 10 per cent changes at 24 hour intervals. They were then placed in 80 per cent alcohol to which had been added a sufficient amount of a saturated solution of iodine in absolute alcohol to make the mixture a cherry red color. In this they remained until they ceased to decolorize the solution, more iodine being added as needed. This time averaged about ten days. They were then passed at 24 hour intervals through 90 per cent and 95 per cent alcohol into absolute alcohol which was changed three times. Instead of passing them directly into the mixture of equal parts of absolute alcohol and ether, they were passed through four intermediate mixtures, each increasing the ether ratio 10 per cent until the 50 per cent was reached. This was an extra precaution to avoid as far as possible shrinkages due to a more sudden change. Ordinary celloidin embedding followed, slow evaporation being used, taking a month or more to reach a firm consistency. The blocks were then hardened in 80 per cent alcohol and transferred through 50 per cent and 30 per cent alcohols into 4 per cent nitric acid for decalcification. They remained in this 12 days, except two groups, one of which remained 6 days and the other 9 days. The fluid was changed daily. They were then transferred to a 5 per cent solution of sodium sulphate, remaining in this 48 hours with one change of fluid; and were then washed in running tap water for 24 hours. The blocks were then "double embedded" in paraffin. They were passed from the tap water through 30, 50, 80, and 95 per cent alcohols, and the dehydration completed with carbol-xylol (crystal carbolic acid one part, xylol three parts). Absolute alcohol can not be used

because of the celloidin present. An intermediate step of equal parts of 95 per cent alcohol and carbol-xylol was used to make the change more gradual. After dehydration with carbol-xylol they were changed to xylol and while thus cleared the blocks were trimmed in such a way that the position of the modiolar axis could be determined later for orientation of the sectioning. They were infiltrated and embedded in 52° C. paraffin in the usual way, the celloidin block containing the cochlea being handled as a piece of tissue.

This method gave in most cases a very fair preservation of the delicate epithelial structures in the cochlea; in a few instances it has failed, these are probably cases where the vascular injection did not penetrate well. The preservation of the tectorial membrane is poor by this method, it is usually found curled back in part of the turns, and it is not so thick as some methods show it to be.

From blocks prepared by this method it is possible to cut thinner serial sections than have usually been employed in studies on the cochlea. From such a block I have an unbroken series of 5 micra sections of a whole guinea pig cochlea, and I have cut some at 3 micra, but not a series. The material used in this study is cut in 7 micra sections; because of the shortage of glassware, especially of large cover-glasses, only every fifth section was saved. It would have been impossible to mount all the series otherwise. From the wide extent of the injured areas reported in the experiments of Wittmaack, Yoshii, and others, it was thought that every fifth section would be sufficient to fully indicate the extent of the injuries. For an exact study of the distribution of injury that I have found unbroken series are needed; every fifth section gives the general distribution of injured areas, but the study of unbroken series might yield additional facts of interest. The sectioning was done with a sliding microtome, using the "water-on-the-knife" method. The blocks were oriented so as to parallel the modiolus as nearly as possible in sectioning; in most cases this was closely approximated, in a few there was some deviation. In most blocks the sectioning was continued until the stapes was reached; in some it was forced to stop sooner either because of imperfect decalcification of the block or because of hard particles in the niche of the round window or elsewhere in this region; these particles are probably grains of sand from the tap water, which was unusually laden with dirt at the time part of the washing was done. The sections were fixed to slides by the usual water-albumen paraffin section method, and were stained with Heidenhain's iron lac hematoxylin; counterstained with benzopurpurin, and mounted in damar. The technic differed from the usual treatment of paraffin sections on slides only in the use of carbol-xylol, instead of absolute alcohol, in passing from xylol to 95 per cent alcohol and back again. This was necessary because of the celloidin present. To completely remove mercuric crystals the sections were passed through an iodine solution in 80 per cent alcohol before the transference to iron alum. The benzopurpurin was used in solution in 95 per cent alcohol; the sections permitted to overstain, and the excess stain removed by fresh 95 per cent alcohol; the slides being transferred to carbol-xylol to stop the decolorization at the desired stage.

## RESULTS

The condition of the labyrinthine parts, here reported, should be compared with the middle ear conditions, previously reported; this can readily be done for the individual ears, as the animal designation has been made in all tabulations.

The injuries to the inner ear have been, for the most part at least, limited to the cochlea. In no case were all of the special sensory areas in the vestibular part of the labyrinth sectioned, owing to the close trimming of the blocks necessary to save glassware. Of those sectioned, many of the maculæ acusticæ and some of the cristæ acusticæ have some shrunken hair cells, but I have no reason to believe that these are more than artefacts. The stapes was reached in the sectioning in 76 of the 92 cochleæ cut; of the 76, all but 10 are in the normal position. In each of these ten cases the annular ligament is broken and the base plate of the stapes tilted more or less into the vestibule. While this condition may be due to the detonations, I am inclined to believe that it was caused by accidents in handling at some time before the celloidin embedding, most probably during the removal from the animal. Therefore these displacements will not be considered further. In both ears of one animal no joint cavity is present about the base plate of the stapes, but this is not a condition which can be attributed to the detonation. The position of the membrana tympani secundaria, closing the fenestra rotunda, is normal, or nearly so, in all cases; it is slightly wavy in some, but no more so than the changing fluids might account for. In part of the membranes there is some edema evident, especially of the middle ear surface. Free blood cells and clots are present on the middle ear surface, but these are the result of the damage to the middle ear parts, already considered. None of the labyrinths have what may be called "gross" lesions, such as the rupture of the walls of the ductus cochlearis or the scala vestibuli or the scala tympani. The occasional bending of parts of the basilar membrane occurs as often in controls as in exposed animals, and is probably due to the embedding. Definite lesions of the organ of Corti and of the spiral ganglion are present in many of the cochleæ. No evidence of extensive internal hemorrhage was found in any of the labyrinths; in some a few isolated blood cells were observed adhering to the scala tympani surface of the basilar membrane. (See Figs. 10 and 13.)

To present the appearance of the lesions observed drawings will be used; they are selected to show the more usual types of injuries.

In speaking of the turns of the cochlea the method of designating by half-turns, beginning at the basal end, has been selected as best adapted to the purposes of this report. Fig. 1 shows in outline a modiolar section with the turns numbered according to the method used. The part in the midmodiolar section is considered as the middle of each half-turn; the junctions of the half-turns have the organ of Corti cut tangentially. Such junctions may be seen in Fig. 2. In speaking of sections of the organ of Corti the term "radial" refers to those in the region of the modiolar sections; the term "tangential" refers to sections in the region of the junction of two half-turns; the term "oblique"

refers to sections in the intermediate region. Fig. 3 is of a normal organ of Corti in radial section, Fig. 4 is of a normal organ in oblique section, and Fig. 12 is of a normal organ in tangential section. The oblique and tangential sections are favorable for the observing of certain of the lesions because several of each element of the organ of Corti are included in each section. The first part of the first half-turn which deviates from the axis of the cochlear spiral and is almost parallel to the modiolus for a distance in the vestibule, has been listed separately in the records made; it is termed the "vestibular part"; Fig. 2 shows the relation of this part of the ductus cochlearis to the rest of the labyrinth. The fenestra rotunda is "beneath" the last portion of the vestibular part.

Figs. 3 to 14, inclusive, are at the same magnification—295 diameters; they are therefore directly comparable, and are at a magnification sufficient to permit ready recognition of parts. The normal sections are inserted for comparison with the injured ones.

The loss of single or of a few adjacent outer hair cells is the definite injury of most frequent occurrence and is evidently the least severe of the definite lesions. Figs. 6, 7, 8, and 13 show sections having such lesions in radial, oblique, and tangential sections. Special features in the various sections are mentioned in the legends (q.v.). Such loss of hair cells is usually associated with a displacement of the corresponding Deiters' cells, frequently showing as a nuclear displacement, as in Fig. 7. Derangements of Deiters' cells without loss of hair cells have not been called injuries in the records made for the reason that they may possibly be artefacts. For some time I was not certain that the absence of isolated hair cells indicated an injury, but after finding such gaps in many of the best preserved cochleæ I have arrived at the conclusion that these are not artefacts. This belief is further strengthened by the increasing frequency of such absences as an area of more severe injury is approached in following the organ of Corti in serial sections. As may be seen in the illustrations given it is possible to have several degrees of severity of such injuries, depending on the proportion of outer hair cells which are missing. It ranges from the loss of a single cell in one section with all the other sections of the region normal, up to the loss of the majority of the cells in all sections for a considerable distance. All these various lesions I have grouped under the term of first degree injury, which may be defined as the loss of part of the outer hair cells with or without derangement of the Deiters' cells.

The absence of all the outer hair cells is the condition found next in order of frequency to the preceding. Fig. 8 illustrates this lesion. This condition may be present in all the sections of a half-turn or more; it ranges from this large extent to a single section. Since only every fifth section has been saved, the presence of this condition in a single section of a series means that it may have extended over any or all of the four sections to either side which were not saved. It will be noted in the illustration that the organ of Corti retains its general outline; this is one of the differentiating points between this injury and the more severe types. This condition, absence of all outer hair cells with retention

of the general shape of the organ of Corti, has been termed second degree injury, for purposes of reference.

Of less frequent occurrence than the preceding condition is that illustrated in Fig. 9. Not only are the outer hair cells missing but also the organ of Corti is crushed out of shape; the illustration shows the usual condition of the filling of the tunnel, Nuel's space, and the outer tunnel space with cellular debris. In some cases there is more or less vacuolization of the mass. It will be observed that the inner hair cell is present, as it is in the other lesions so far described. This condition does not, in my material, occur in isolated sections, but areas so injured are always adjacent at one end, and usually at both, to areas of lesser or of greater injury. This condition, absence of outer hair cells associated with a general crushing of the organ of Corti with massed or vacuolized debris in the large spaces of the organ, has been termed third degree injury.

A more severe lesion of the organ of Corti is that illustrated in Figs. 10 and 14. In this lesion the outer hair cells are all absent, the organ of Corti is badly broken up, the cellular debris is usually vacuolized but may be massed as in the typical third degree injury, and the inner hair cell is absent. The cells of the internal spiral sulcus are frequently vacuolized. This condition has been termed fourth degree injury, and is characterized by the severe disintegration of the organ of Corti with absence of the inner hair cell, which is, of the special sensory epithelial cells, the least often missing. In only one instance was the inner hair cell observed in an abnormal condition when the rest of the organ of Corti in that section was normal. Two adjacent sections of a series (every fifth section saved) show a chromatolysis of the inner hair cell. In one of these two sections there is no other injury evident; the other section has part of the outer hair cells missing. Elsewhere definite lesions of the inner hair cells have been observed only in association with severe injuries to the rest of the organ of Corti. This fourth degree injury, like the third degree, is not found in isolated sections in otherwise normal areas, but areas of it are bounded by areas of lesser degree of injury.

Fig. 11 shows the most complete destruction of the organ of Corti which is present in my material; it occurred in a zone of fourth degree injury, and since it occurred but once I have not given it a special designation of degree.

The distribution of the lesions of the organ of Corti in the various cochleæ studied is shown in the charts of Plate IV. In making these charts the relative lengths of the various half-turns have been approximated, instead of showing each half-turn as of the same value. To indicate the various degrees of injury three shades of grey, parallel lines, and dots have been used. The darkest shade of grey represents the condition that has been termed fourth degree injury; the intermediate grey, third degree injury; and the light grey, second degree injury. The narrowest of these light grey zones represent single sections, though they are proportionately too wide for the actual ratio which a single section should cover in the chart. The parallel lines indicate areas where all sections are in the condition termed first degree injury; and the dots indicate first degree injury in isolated sections. Where two or three

adjacent sections are in this condition it has been shown by drawing a line underneath the dots, unless it is between zones of more severe injury, in which case parallel lines have been used. The number of dots is not, in most cases, the exact number of sections with lesions but the number of dots indicates the relative frequency of sections showing injury to the organ of Corti. Since only every fifth section has been saved, the absolute distribution can not be determined from these series. The position of the ends of the injured areas can be determined only by means of graphic reconstruction which allows for the difference in length of the part of the organ of Corti contained in radial, oblique, and tangential sections. I have devised a suitable method for making such graphic reconstructions, but have not used it here since most of its value over the method of approximation would be lost due to having only every fifth section. In studying the cochleæ the organ of Corti and other structures were followed section by section from the vestibular end of the cochlear duct to the apical end, being traced back and forth through each series for the different turns. The notes, from which the charts presented were made, were jotted down at the time of observing injured areas during these examinations of series.

For convenience of reference, the conditions recorded have been grouped in four charts.

In Chart I are placed all cases where the outer ear was entirely open and the detonation used was one shot from a 45 caliber Colt automatic pistol with the muzzle at 15 cm. from the ear. Most of these are the open ears of animals in which the other ear was "protected;" in all cases the 15 cm. was measured from the opposite ear, and the barrel pointed downwards about 20 degrees along the left side from above and in front.

In Chart II are presented the controls with the open rubber ear and glass tubes of various sizes. From a study of the great variations in individual cases in the cochleæ recorded in Chart I, where all were exposed to as similar traumatic conditions as possible, it is evident that the number of controls with each tube is too small, there being only one with each, except with the 2 mm. tube, and in this case the extra two animals were used because wax entered the end of the tube during the experiment (cf. middle ear observations).

In Chart III are presented the conditions of the cochleæ of the "protected" ears. To facilitate comparison, these have been arranged in the same order as the middle ear observations on the protected ears (q.v.).

In Chart IV are presented the conditions of the cochleæ of animals submitted to detonations other than the usual one shot at 15 cm.

Besides these, two animals were taken as controls of the possible injury to the ears while in the basket during the experiment with others. One of these, animal 62, was also placed in the holding apparatus as a control of possible injuries by this procedure. The other, animal 63, simply remained in the basket during six experiments, being exposed thus to the sound of six shots from the pistol at a distance of about 25 feet, the gun pointing away from the

basket. Both cochleæ of animal 62 are entirely normal. The left cochlea of animal 63 has a few sections with missing or distorted outer hair cells in the sixth half-turn; the right cochlea has about 30 isolated sections with some outer hair cells missing, scattered throughout its length except in the vestibular part and the eighth half-turn; the injured sections are most numerous in the third to the sixth half-turns.

Shrinkage and chromatolysis of part of the cells in parts of the spiral ganglion are present in many of the cochleæ; this condition is present most often in the vestibular part and first half-turn; less frequently it is present in the second, third and fourth half-turns, and occurs very seldom above this level. In general the distribution corresponds with the injuries to the organ of Corti, but there are many exceptions to this general arrangement. In the vestibular part and first half-turn shrunken ganglion cells are much more frequently present in the cochleæ of unprotected ears than the protected ones in which definite lesions of the organ of Corti occurred; and in these unprotected ears the number of shrunken ganglion cells frequently appears to be a much greater proportion of all the cells than the proportion of hair cells missing in the corresponding region. On the other hand, in many cases the ganglion cells show no injury in regions corresponding to parts of the organ of Corti that were severely injured. The possibility must always be kept in mind that these ganglion cell alterations may be artefacts; but after observing many cases where the occurrence of a zone of injury corresponds to a zone of ganglion cell shrinkage and protoplasmic change I am of the opinion that these indicate a true lesion. Animals allowed to live a longer period of time after being submitted to detonations are needed to definitely settle this point. In two cases all the ganglion cells were in bad condition, but in both of these the general fixation was so poor that the alteration is in all probability an artefact. In a few cases some of the nerve fibers leading from the ganglion to the organ of Corti are definitely degenerating; in most cases they appear nearly, if not entirely, normal. The fibers in the organ of Corti itself can not be seen in the sections of the more severe lesions.

A peculiar condition is present in the cochleæ of animal 44. The ductus cochlearis, sacculus, and utriculus are distended to an unusual size. Reissner's membrane is bulged into the scala vestibuli and is longer than normal. It is not thickened. The walls of the utriculus and sacculus are similarly distended. The distention is somewhat less in the right cochlea. The right cochlea of animal 37 has a similar, but much less distended, condition from the basal end to the fifth half-turn, and the second and third half-turns of animal 27 show it in slight degree. In the one with the greatest distention, the left cochlea of animal 44, the stria vascularis of most of the third half-turn and of part of the first half-turn has a peculiar enlargement of the blood vessels. The enlargement of the blood vessels of the stria vascularis and the distention of the endolymphatic channels of the left cochlea of animal 44 may

be associated as cause and effect but it seems doubtful in view of the facts that enlarged vessels are not present in the other cases of distention and that several cases of enlarged vessels, though of much less extent, are present in cochleæ where no distention has occurred. I wish to specifically state that I am undecided whether either the enlargement of the vessels of the stria vascularis or the distention of the endolymphatic channels has been caused by the detonations.

## DISCUSSION OF RESULTS

In discussing the above observations upon the labyrinths their bearing upon the relative efficiency of the various protective measures will be considered first and the evidence from the three sets of observations which I have made correlated. Then a comparison will be made of the lesions in my material with those recorded by other observers upon detonation injuries of the labyrinth, and the bearing of the results upon the general problem of the physiology of hearing indicated.

I. *Relative Efficiency of Protective Measures.*—The condition of the middle ear parts and the tambour results, reported previously, both indicated a division of the protective measures into two distinct groups on the basis of their relative efficiency in preventing the passage of the force of the detonation waves used; these two sets of results agree in the devices which would be placed in each group. Dry cotton, the Elliott protector, and the Wilson-Michelson instruments are in the less efficient group. Examination of Chart III shows that the division into groups on the basis of the cochlear results is not so well marked; each of the protective measures failed to prevent definite cochlear lesions in one or more of the ears with which it was used. Even here, however, a ranking of the devices is evident; and two of the three protective measures which are in the less efficient group on the basis of the other tests again rank lowest.

It may be that one of the groups of observations is of more value than the others; if so, this should receive the most consideration in drawing conclusions. I would call attention to the fact that the animal experiments are the ones which indicate the devices that permit an injurious amount of detonation waves to pass; the physical experiments are of value in helping to place the preventives in their relative order of efficiency. The tambour method, on the other hand, has the advantage which all experiments in physics have over biologic work; *i. e.*, the materials used are not subject to the individual variations which the reactions of living organisms are. It is evident from the great variations in the cochlear injury in the cases where the ear was open and the conditions were as similar as possible that there is either a great individual difference in guinea pigs in the degree of susceptibility to injury of this type or an entirely unrecognized factor acting to modify the detonations (see Chart I). In the conduction of the animal experiments with protective measures there are opportunities for errors in technic; they were recognized and guarded against, but the possibility must be kept in mind that in some cases the wax packing used may not have completely prevented the entry of injurious force through the

crevices around the tube which it was supposed to close, or that the device may not have been properly placed in the rubber ear. The former error is the more probable: the latter is one that is more likely to occur in the use of devices by troops than under laboratory conditions. If it were not for the great individual differences in the long series of controls (Chart I), I would be inclined to think that the possible errors mentioned above had occurred often, and that therefore the cochlear results were almost worthless as a basis for comparison of the relative efficiency of the devices. But, if such were the case, the question immediately arises as to why the middle ears were not also damaged in a like ratio. As a possible explanation of the discrepancy here might be advanced the general belief for many years among otologists that in cases of air wave trauma of the ear the injury to the labyrinth is less when the tympanic membrane ruptures than when it remains intact; the explanation advanced is that the force is expended in rupturing the tympanic membrane. The statements are based upon clinical experience. Yoshii (1909) reported one animal which has a bearing upon the subject. In this case a guinea pig was exposed to the detonation from the firing of a revolver at 20 cm. (size of gun and position with reference to the animal not given). At autopsy it was found that the right middle ear was badly damaged while the left middle ear was entirely normal. Study of the cochleæ showed the right one to be entirely normal, while the left one showed "very light degree alteration." From his description the alteration is less than anything I have called a definite lesion. This case agrees with the clinical view. In my material, animals 17 and 18 were the only ones in which, under similar conditions for the two ears, one tympanic membrane remained intact and the other ruptured. In animal 17 the cochlea of the side with the normal middle ear was severely injured, while the other cochlea was only slightly injured. In animal 18 difficulties in technic prevent any definite statement as to the cochleæ. Since the tympanic membrane was ruptured in all cases of open ears exposed to the usual detonation, no comparison is possible in this series. However, there are many cases here, and in the controls with the open rubber ear and glass tube, in which the cochlea was severely injured. Of the ears with which dry cotton, the Elliott protector, and the Wilson-Michelson instrument were used, all had damaged middle ear parts; one of each group of three had the tympanic membrane ruptured, though less severely than in most of the cases of open ears. With dry cotton, the cochlea of the ear with a radial slit in the tympanic membrane is definitely injured; the injury to this cochlea is greater than to one of the other two, and less than the injury to the third one. With the Elliott protector the cochlear injury is much less in the case with a ruptured tympanic membrane than in the two where it remained intact. With the Wilson-Michelson device the cochlear injury in the case of the ruptured tympanic membrane is about the same as in one of the other two and less than the injury in the third case. With the rest of my material such comparisons can not be properly made, because the force of the detonation waves reaching the ears varied greatly, due either to different protectors or to dif-

ferent distances used. While some of my cases are in accordance with the idea that rupturing of the tympanic tends to protect the labyrinth, it seems to me, on the whole, that the exceptions to the rule are too numerous to accept it as an explanation of the inconsistency between the middle ear and the cochlear conditions. In this my material agrees with the clinical experience of Meyer with troops submitted to modern battlefield conditions. It seems improbable that a true "bone conduction" can have played much, if any, part here, since the vibrations would have had to pass through a person's body to reach the ground on which the animal rested.

The condition of the cochleæ of animal 63, used as a control for possible injury while in the stock basket during the testing with other animals (see page 7), was a surprise to me, as I fully expected this control to be normal; animal 62 had both cochleæ entirely normal. There is a possibility that the lesions present, outer hair cells missing in isolated sections, are not due to detonations, in which case all the lesions of this nature would have to be ruled out of consideration. On the other hand, if they are due to the detonations of the pistol at the distance at which the basket was placed, (25 feet with the gun pointing in the opposite direction), all the cases of such "isolated section" lesions must be considered as possibly due to such an origin and their bearing on the protection afforded by devices thrown out. At the time of the experimentation I considered the distance sufficient to avoid any such complication; at present I must leave the question of interpretation open. Here, as in the other groups, variation has occurred; one animal normal and one injured (?).

As the most suitable way of determining the ranking given by the combined tests to the protective measures, the method of adding the rankings given by the different tests has been chosen. All three sets of observations are given the same value by this method. The devices tested only by the tambour method are omitted in this tabulation. To determine the order of efficiency as given by the tambour method the results with the three guns used are ranked. When two devices are tied for a place, the sum of this and the next lower ranking is halved and each of the devices given this number. (See Tables I and II.)

The ranking arrived at by this method is open to criticism, and is, at best, only an approximation. The division into two groups is very definite, however; and the other requirements for military use should be the deciding factor in choosing from the more efficient group, rather than the slight differences in the laboratory results with these protective measures. These other factors have already been considered in the previous reports and need not be taken up here. It suffices to state that the "Tommy" is the best of the mechanical devices from the standpoint of general military requirements for field use by troops, and since it has a slight advantage over the others in the laboratory tests it is the protective measure which seems to be indicated for a large field trial. On the other hand, the results of the laboratory tests seem to eliminate the need of field trials by troops of dry cotton, the Elliott protector, and the Wilson-Michelson device.

11. *Comparison with Previous Work on Detonation Injuries.*—The extent and distribution of the injuries to the organ of Corti in the animals I have used are quite different from those reported by Wittmaack, Yoshii, and Prenant and Castex, but are similar to some of Hoessli's and of Hoshino's cases. With the exception of some of Hoessli's experiments all the animals used by other workers have been exposed to detonations with the ears entirely open. Wittmaack's statements are very indefinite regarding his detonation cases; some animals were negative, and no statement is made of the extent of the injured area in the ones which were injured. The one figure which he presented of a detonation injury is from the next to the highest turn (fifth and sixth half-

TABLE I

RANKING OF THE DEVICES BY THE TAMBOUR METHOD

| PROTECTIVE MEASURE | RANKING ACCORDING TO | | | SUM OF RANKINGS | RESULTING RANKING |
|---|---|---|---|---|---|
| | 22 CALIBER | 38 CALIBER | 44 CALIBER | | |
| Vaselined cotton | 1½ | 1 | 2 | 4½ | 1 |
| "Tommy" | 3 | 2½ | 1 | 6½ | 2 |
| Glycerined cotton | 1½ | 4 | 3 | 8½ | 3 |
| Mallock-Armstrong | 4 | 2½ | 5 | 11½ | 4 |
| Wax cone | 5 | 5 | 4 | 14 | 5 |
| Wilson-Michelson | 8 | 6 | 6 | 20 | 6½ |
| Elliott Protector | 6 | 7 | 7 | 20 | 6½ |
| Dry cotton | 7 | 8 | 8 | 23 | 8 |

TABLE II

RANKING OF DEVICES BY THE AVERAGE OF THE THREE SETS OF RESULTS

| PROTECTIVE MEASURE | RANKING ACCORDING TO | | | SUM OF RANKINGS | RESULTING RANKING |
|---|---|---|---|---|---|
| | TAMBOUR METHOD | MIDDLE EAR CONDITIONS | LABYRINTH CONDITIONS | | |
| "Tommy" | 2 | 1 | 4 | 7 | 1 |
| Mallock-Armstrong | 4 | 2 | 3 | 9 | 2½ |
| Glycerined cotton | 3 | 5 | 1 | 9 | 2½ |
| Wax cone | 5 | 3 | 2 | 10 | 4 |
| Vaselined cotton | 1 | 4 | 6 | 11 | 5 |
| Elliott Protector | 6½ | 7 | 7 | 20½ | 6½ |
| Wilson-Michelson | 6½ | 6 | 8 | 20½ | 6½ |
| Dry cotton | 8 | 8 | 5 | 21 | 8 |

turns of my terminology); it resembles somewhat the lesion I have termed third degree injury. A study of this and other figures given by Wittmaack leads me to agree with the group of workers in Siebenmann's laboratory at Basel; *i. e.*, there are many artefacts due to faulty histologic technic in the work of Wittmaack, so that even his indefinite statements must be discounted. As in all of his work on cochlear injury by sound waves Wittmaack considered the injury to the ganglion cells the primary lesion and the epithelial degeneration secondary. The lesions found by Yoshii in the middle ears were very similar to those of my unprotected animals. The two figures given by him of the organ of Corti after exposure to single detonations show a condition which agrees with that which I have termed fourth degree injury. (An ex-

tensive quotation from Yoshii's description of the lesions observed by him was given in the report on the literature, page 851 of the September, 1917, Journal of Laboratory and Clinical Medicine, to which the reader is referred.) He reported this severe lesion as present the whole length of the cochlea, which is a lesion more extensive than is present in any of the animals I have used. He also reported changes in the ganglion cells, and he, like the rest of the Siebenmann group of workers, considered these to be secondary degenerations and the epithelial primary. He also mentioned hemorrhage into the spaces of the labyrinth in some cases. The size of the gun used by Yoshii was not definitely stated; he merely said, "Diese Versuche wurden teils mit einer Kinderpistole und blossen Zündhütchen, teils mit Revolver und Patronen unmittelbar vor der Ohrmuschel und zwar jeweilen an beiden Ohren rasch nacheinander ausgeführt." He placed the muzzle of the gun much closer to the ear than I did, and in reality exposed each ear to two detonations; for my experiments show that both ears are damaged at much greater distances than that between the two ears of the guinea pig. This closer range may account for the more extensive injury his animals received. He used eight animals in this series; two were killed immediately, and one each after 2, 3, 8, 25, 45, and 60 days respectively. In view of my results it seems probable that more animals might have given him more variation. In any case, his statements as to some regeneration having occurred in the animals killed after the longer intervals certainly needs confirmation with a greater number of animals for each stage.

Hoessli, in his first series with detonations, was testing primarily air and bone conduction, to determine which transmits the injurious force. He used three guinea pigs with the incus removed on the left side of each, and two animals with moistened cotton in both ears. All were placed in a cage and a Swiss army revolver was fired five times at about 30 cm. above them. They were killed 24 hours later. Each animal was reported by a separate protocol. In none of the cases was there any damage to the middle ear parts, other than the operative injury in the animals with the incus removed. All three of the cochleæ in the cases with the incus removed were normal, as were also three of the four ears which had moistened cotton in the external meatus. In two of the three open ears with normal middle ear parts and one of the cotton protected ears the cochleæ had lesions in the organ of Corti in the lower half of the second turn (third half-turn of my terminology). The injury as described agrees with what I have termed third degree injury; Hoessli noted that the inner hair cells were present, and stated that there was no evidence of injury to the ganglion cells or nerve fibers, except the fibers in the organ of Corti itself. Except for this half-turn he reported the cochleæ normal. Of the third case of open ear with normal conducting apparatus, he said: "Die Scala cochleæ ist im ganzen normal und zeigt keine Veränderungen. Einzig an derjenigen Stelle, wo wir in Fall 22 die ausgedehnten Veränderung vorfinden, sehen wir hier einen teilweisen Mangel der äusseren Haarzellen bei sonst normalen Cort. Organ. Die übrigen Skalateile

sind ebenfalls normal." Apparently this was a slight injury; Hoessli was properly very cautious as to the interpretation of possible artefacts. In those of Hoessli's cases which are comparable to mine, cochlear injuries occurred in the same region where mine show the most frequent injury; *i. e.*, the third half-turn. The condition of the unprotected middle ear parts in his cases shows that he was working with a less powerful wave than I have used, for no injury to the middle ear parts occurred. Hoessli believed that the one case where the wet cotton failed to protect was due to the scratching loose of the cotton by the animal. He followed this series by one in which he used four cats, the left ears stopped with wet cotton, the right ears left open. To prevent scratching out of the cotton the animals were lightly narcotized and five shots were fired at 25 cm. above the four of them. As before, the animals were killed 24 hours later. The left ears in all cases were normal. In three of the four right ears there was an area in the upper part of the basal turn (upper part of second half-turn) extending through about 15 sections (thickness of sections not stated) where a slight variation from normal was found; the variation consisting of a depression of the organ of Corti in the region of the outer hair cells. The fourth case was entirely normal. In view of the variations in individual cases in the longer series I have used the two exceptions in Hoessli's short series are interesting.

While Hoessli was interested primarily in the question whether air or bone conduction transmits the injurious waves, he called attention to the bearing of the results with wet cotton to the protection of soldiers. All that he says of this phase of it is here quoted verbatim: "Hier denkt man unwillkürlich an die vielen Fälle von Schusstrauma bei Soldaten, welche Watte in den Ohren getragen haben sollen. Wir sehen eben hier, dass wenn der Wattepfropf nicht ganz fest sitzt, und am Ende gar nicht angefeuchtet ist, der Schutz des Ohres ganz illusorisch ist."

The region in which the majority of the lesions have occurred in my material is in general the same as was injured by the various guns used by Hoshino (1917).* He exposed guinea pigs to the detonations of a medium-sized revolver, a hunting gun, an army rifle, and a cannon. With the small arms blank cartridges were used and in most cases the shooting was directly toward the ear, at distances varying from "close up" to 100 cm.; two series were run with each gun, in the first group of series one shot was fired toward each ear of each animal, in the second group several shots each, the number varied from 5 to 350. The cannon was one used as a "time piece" and was loaded with only about four pounds of powder; the animals were placed two meters in front of the muzzle; they were blown as much as twenty meters by the explosion. Two animals were exposed to one shot each and two to five shots each. The animals of the various series were killed at intervals varying from "immediately" to fifty days after exposure. The greater number of animals were handled by an injection fixation, using Held's formal-bichromate-acetic

*It is to be regretted that the observations of this Japanese otologist are recorded in a language which renders them inaccessible to so many investigators. I desire to here express my thanks to Dr. I. Watanabe, an assistant in this laboratory, for reading this article to me.

mixture. The resulting injuries to the labyrinth were more severe and widespread in the cases where many shots were fired than in those "once exposed" (really twice since each ear was considered separately in counting the shots), but were in the same region of the cochlear canal for each gun, whether one or many detonations were used. Hoshino reported that the region of most severe injury varied for the different guns; it was lowest for the cannon and highest for the revolver. The regions for each were: (1) revolver, second turn and lower part of third; (2) cannon, upper part of basal and lower part of second turn; (3) army rifle, upper part of basal turn; and (4) hunting gun, lower part of second turn. One monkey was used, it was exposed to one detonation from the rifle held close to the ear. The injured area extended the whole length of the cochlea in this case, but Hoshino thought the wide extent possibly due to the short distance rather than to the different type of animal. The injuries to the organ of Corti varied from minor atrophic changes to complete destruction and replacement by a simple epithelium. Hoshino also broke the tympanic membranes of six animals and introduced staphylococci into the middle ears, waited until a suppurative otitis had developed, and then exposed them to detonations from the small arms. He found in general the same type and extent of injury due to detonation as in the animals with normal middle ears similarly treated. He added this suppurative otitis evidence in support of the view that impaired conducting apparatus does not protect the labyrinth from detonation injuries. Hoshino reported lesions involving the tectorial membrane, which was sometimes "frayed out" and sometimes almost entirely missing. While the technic used on my material is not favorable for the study of the tectorial membrane, because of the way it is shrunken and frequently turned up even in normal cases, I have observed no evidence that it has definite lesions due to detonations. While Hoshino stated that the area injured was more extensive with repeated detonations than with one, he did not mention variations in extent under identical conditions, such as my material shows. The small amount of powder used in the cannon and the fact that no shell was used would indicate that the intensity of the detonation was not so great as that of the majority of artillery pieces and exploding shells, but the placing of the animals in front of the muzzle where they were hurled twenty meters by the explosion simulated to a degree the conditions in the battle field where men are frequently hurled by the blast of an exploding shell and at the same time exposed to the intense sound. It is of interest to note that the lesions produced by Hoshino's cannon were of the same nature as those produced by the smaller detonations of both himself and others; this indicates that the study of lesions due to relatively small detonations are of value in interpreting the effects of more intense explosions.

Prenant and Castex (1916) placed animals in cages near large caliber guns at Fontainebleau. In no case was the tympanic membrane ruptured or the middle ear inflamed; ten guinea pigs and six rabbits were used. The preservation of the labyrinths was poor; they reported extensive cochlear lesions of the type to be expected from previous work in this line with smaller

guns. Since this is the only work in which animal cochleæ have been reported after exposure to detonations of such large guns as they used, it is very much to be regretted that the histologic technic used gave such poor results, for this makes them of very little value except for very indefinite comparisons and conclusions.

The report of J. S. and John Fraser (1917), made upon autopsy material from soldiers deafened by detonations, must be considered in the light of the histologic technic employed by them, which was such as to render the results very indefinite, as they realized. Hemorrhage into the labyrinth and about the entrance of the nerve roots in the fundus of the internal meatus were definite findings of interest. It is almost impossible in their material to differentiate the artefacts from the actual lesions in the organ of Corti and nervous tissues. Wilson reported recently (*Journal of the American Medical Association*, August 24, 1918) the condition of a temporal bone secured at autopsy six hours after the death of a soldier who had been deafened by a shell explosion. (Wilson said that two were reported in the Harvey lecture which he gave; but this is not yet available to me.) Formalin fixation was used. He, like Fraser, reported hemorrhage in the base of the internal auditory meatus. There was very evident damage to the cochlear parts; edema and small cell infiltration were mentioned as being present in the ganglion, stria vascularis, basilar membrane and organ of Corti. The epithelial cells and the ganglion cells were "indistinct," doubtless due in part, at least, to the time after death before placed in fixative and to the necessarily slow penetration of the fixative, even though the superior semicircular canal was opened.

The presence in my material, except in the most severe injuries, and also in Hoessli's detonation cases, of the inner hair cells is interesting in connection with Hoessli's observations on injury by the sound from organ pipes; he found the inner hair cells intact after the outer hair cells had disappeared and even sometimes when the supporting apparatus of the outer hair cells had broken down. These facts indicate either that the inner hair cells are more resistant to injurious sound waves, or that they do not receive as great intensity of the waves as do the outer hair cells. This is not taken into account in any of the theories of hearing. The statement of Shambaugh (1911) that the ciliæ of the outer hair cells are in constant contact with the tectorial membrane while those of the inner hair cells are free is suggestive in this connection.

None of the reports of previous experimental work involving detonation injury of the cochlea make any mention of separated zonal lesions, which are so plentiful in my material. (See, for example, "34 Rt." in Chart I.) It is evident that if the variations in sound waves are perceived by any type of peripheral analysis, the occurrence of definite zones of injury to the organ of Corti indicates that the parts injured were most active in converting the sound waves into nervous energy. In other words, if either the Helmholtz theory in its original form or in any of its modifications, or the Lehmann or the Ewald or the Köhler theory, or the theories involving the tectorial membrane as a differentiating mechanism, are correct, injured zones of the organ of Corti

are to be interpreted as being in the areas of resonance for the sound waves that caused the damage. If there is any definite pitch, or if there is a mixture of vibration frequencies in the sound waves produced by the firing of a 45 caliber pistol, it seems reasonable to suppose that it will not vary with different shots to the extent that would cause the difference in cochlear lesions observed under otherwise identical conditions; that is, open ears at the same distance and direction from the gun. No attempt has been made to obtain and analyze sound curves from the detonations used, so that no conclusions can be reached along this line.

A general view of Chart I, in which are presented the cochlear conditions in the open ears exposed to the firing of one shot at 15 cm. from the muzzle of a 45 caliber Colt automatic pistol, reveals that the average center of the injured areas, other than isolated sections of first degree injury, is in the third half-turn, except for the few cases with severe injury in the vestibular part and first half-turn. The making of the charts with the relative lengths of the half-turns indicated permits the ready recognition of the fact that the center of the total length of the cochlear duct of the guinea pig is also in the third half-turn. In Chart III, in which are presented the cochlear conditions in the "protected" ears, the average center of the injured areas is somewhat higher; and there is almost complete absence of injuries, even of the first degree in isolated sections, in the whole of the basal turn (vestibular part and first and second half-turns) of all the cochleæ, except those in the Elliott and Wilson-Michelson series.

These observations of separated zones of injury and the average grouping of the same are presented and attention called to them in the hope that they may prove of value at some time, in connection with other data, in solution of the problem of the physiology of hearing.

It is a pleasure to express here my appreciation of the valuable suggestions made by my chief, Dr. Huber, during the course of this work.

### RESUMÉ OF ALL MY REPORTS UPON WAR DEAFNESS AND ITS PREVENTION

1. Laboratory methods for the testing of measures for the prevention of detonation injuries to the ear have been devised and such tests have been carried out upon various protective measures.

2. These tests indicate that the measures tested may be divided into two definite groups upon the basis of their efficiency in preventing the passage of the force of the detonation waves used; the variations within each group are less decisive. In the more efficient group are the Scientific Ear Drum Protector "Tommy," the Mallock-Armstrong Ear Defender, cotton soaked with glycerine, cotton soaked with vaseline, and the wax cone of the Italian navy type. In the less efficient group are dry cotton, the Elliott Perfect Ear Protector, and the Wilson-Michelson device.

3. The cochlear lesions produced by the detonations differ in extent and distribution from those hitherto reported; the injury areas are frequently separated by normal zones; these lesions are recorded in a graphic form which

makes them more available for reference than if the usual method of written protocols had been followed. The facts are presented without drawing theoretical conclusions as to their bearing on the physiology of hearing.

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## Explanation of Figures

### ABBREVIATIONS

*a.*, Apical end of ductus cochlearis.
*c.C.*, Cells of Claudius.
*c.D.c.*, Cuticular processes of Deiters' cells (basal part).
*c.H.*, Cells of Hensen.
*c.i.s.*, Cells of internal spiral sulcus.
*f.r.*, Membrana tympani secundaria closing the fenestra rotunda.
*g.sp.*, Ganglion spirale.
*i.h.c.*, Inner hair cells.
*i.p.*, Inner pillars.
*l.o.*, Lamina spiralis ossea.
*l.sp.*, Spiral ligament.
*m.b.*, Basilar membrane.
*m.ret.*, Membrana reticularis.
*m.v.*, Membrana vestibularis (of Reissner).
*n.*, Nerve fibers in the spiral osseous lamina.
*n.c.* Cochlear nerve.
*n.D.c.*, Nuclei of Deiters' cells.
*n.o.p.*, Nuclei of the outer pillar cells.
*N.s.*, Nuel's space.
*o.h.c.*, Outer hair cells.
*o.h.c.*1, Outer hair cells of the first row.
*o.h.c.*2, Outer hair cells of the second row.
*o.h.c.*3, Outer hair cells of the third row.
*o.p.*, Outer pillars.
*o.t.s.*, Outer tunnel space.
*ph.pr.*, Phalangeal processes of Deiters' cells.
*sac.*, Sacculus.
*s.t.*, Scala tympani.
*s.v.*, Scala vestibuli.
*t.f.*, Tunnel nerve fibers.
*t.s.*, Tunnel space of the organ of Corti.
*utr.*, Utriculus.
*v.p.*, "Vestibular part" of the ductus cochlearis.
*v.sp.*, Vas spirale.

## Legends for Plate I

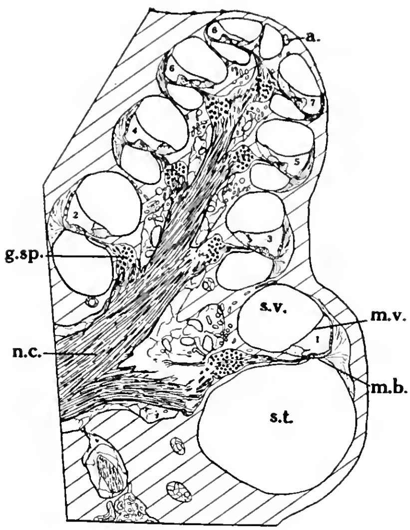
FIG. 1.—Outline drawing of a mid-modiolar section of a left cochlea of a guinea pig. Guinea pig 55, left cochlea, slide 1, row 4, section 1, 15×. The arabic numerals in the various sections of the ductus cochlearis indicate the designation of half-turns as used in this article. The part in the modiolar section is considered as the center of each half-turn; the junctions of the half-turns are in the sections which cut the curve of the organ of Corti tangentially.

FIG. 2.—Outline drawing of a section of a right cochlea of a guinea pig to one side of the modiolar axis, showing the position of what has been termed the "vestibular part" of the ductus cochlearis and the relations of parts in "oblique" and "tangential" sections. Arabic numerals as in Fig. 1. Guinea pig 21, right cochlea, slide 2, row 1, section 2, 15×.

FIGS. 3 to 14, inclusive, were drawn with the aid of a camera lucida at a magnification of 885 diameters, and have been reduced in reproduction to 295 diameters, one-third of the original size of the drawing. Being at the same magnification, comparison is facilitated. Figs. 3, 4, and 12 are drawings of sections of the organ of Corti in normal condition, and are presented for comparison with the ones having lesions. All the cochleæ were prepared by the same technic and the sections used for illustrations were selected to present the typical lesions observed. See the text matter for the technic and the terminology used in designating the lesions.

FIG. 3.—Drawing of a normal organ of Corti in radial section. Guinea pig 21, right cochlea, slide 1, row 4, section 8, second half-turn, 295×. As is well known, the shape of the organ of Corti varies in the different parts of the ductus cochlearis; allowance must be made for this in comparing this drawing with those of lesions in other parts of the cochlea.

FIG. 4.—Drawing of a normal organ of Corti in oblique section. Guinea pig 41, right cochlea, slide 1, row 5, section 2, second half-turn, 295×.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n.c.
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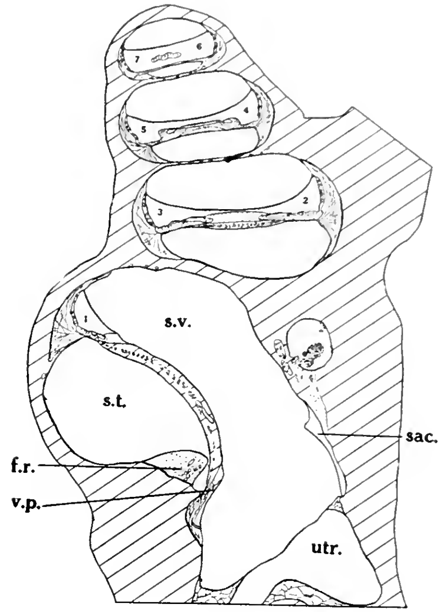
m.b.
s.t.

1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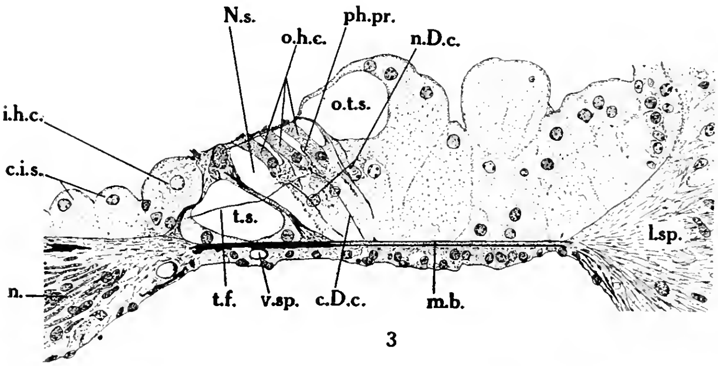
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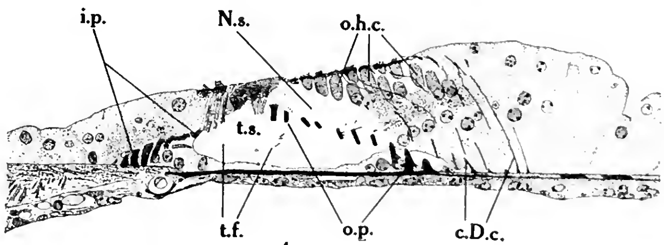
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Plate I.

## Legends for Plate II

FIG. 5.—Organ of Corti, with first degree injury, radial section. Guinea pig 52, left cochlea, 1-4-7, third half-turn, 295×. The outer hair cells of the second and third rows are missing.

FIG. 6.—Organ of Corti, with first degree injury, radial section. Guinea pig 30, left cochlea, 1-6-2, first half-turn, 295×. The outer hair cell of the first row is absent, and the nucleus of the corresponding Deiters' cell is displaced downwards.

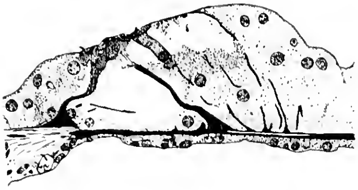
FIG. 7.—Organ of Corti, with first degree injury, oblique section. Guinea pig 47, right cochlea, 1-5-5, second half-turn, 295×. Compare with Fig. 4. Some of the cells of each row of outer hair cells are missing.

FIG. 8.—Organ of Corti, with second degree injury, radial section. Guinea pig 40, left cochlea, 1-3-2, fourth half-turn, 295×. All the outer hair cells are missing and the Deiters' cells are partially destroyed. Note that the general shape of the organ is retained; it is different from that of Fig. 3, but is the normal outline for this part of the cochlea.

FIG. 9.—Organ of Corti, with third degree injury, radial section. Guinea pig 29, left cochlea, 1-3-6, fourth half-turn, 295×. The shape of the organ is lost, being crushed; there is cellular debris in the spaces of the organ; the outer hair cells are missing; the reticular membrane in this case is broken and pieces of it are seen scattered through the mass.

FIG. 10.—Organ of Corti, with fourth degree injury, radial section. Guinea pig 28, left cochlea, 1-4-2, third half-turn, 295×. The severity of this type of lesion may be seen at a glance; all the essential parts of the organ of Corti have been destroyed. Adhering to the scala tympani surface of the basilar membrane may be seen two red blood cells and one leucocyte; this is one of the few cases where even this much hemorrhage was observed.

FIG. 11.—Drawing of a section in which the organ of Corti has been almost entirely replaced in 48 hours by a simple epithelium. Guinea pig 50, left cochlea, 1-4-9, third half-turn, 295×. This is the only instance in my material in which the destruction is so complete. I have not given it a designation of degree as was done with the types of lesions which occurred often.



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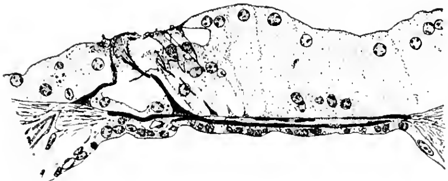

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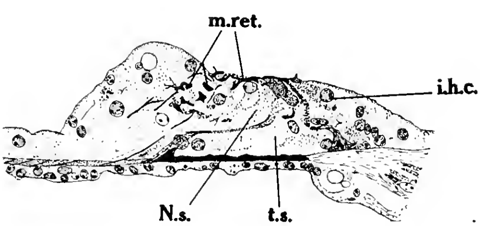


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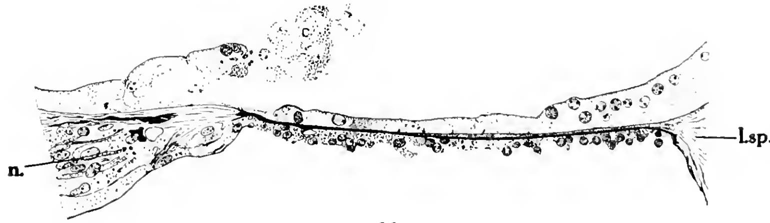


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Plate II.

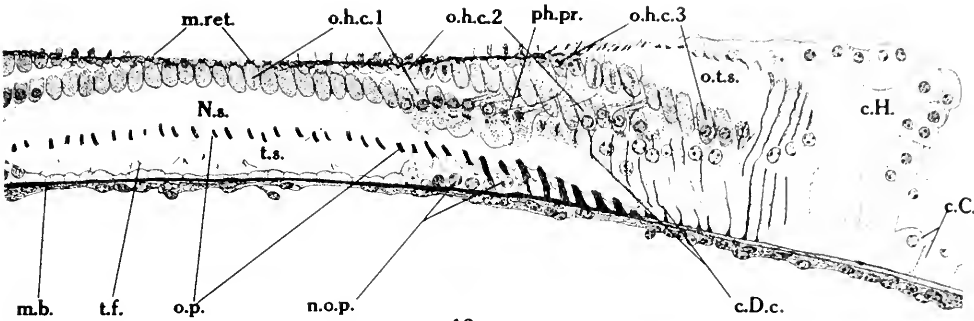
## Legends for Plate III

FIGS. 12, 13, and 14 should be compared directly in order to interpret readily the lesions shown in 13 and 14. All three are drawings of sections which have been selected as being of corresponding parts of the various organs of Corti. The elements of the organ of Corti have been labelled in Fig. 12 only; reference should be made to it in studying Figs. 13 and 14. Oblique and tangential sections are favorable for observing lesions because of the number of each element present in a single section.

FIG. 12.—Normal organ of Corti in tangential section; the plane of section is parallel to the modiolar exis. Guinea pig 33, left cochlea, 1-5-6, junction of fourth and fifth half-turns, 295×.

FIG. 13.—Organ of Corti with first degree injury, tangential section. Guinea pig 27, left cochlea, 1-5-2, junction of fourth and fifth half-turns, 295×. When compared with Figs. 5 and 6, which are of radial sections of the organ of Corti, the nature of this lesion is better understood; a few or even single outer hair cells are missing in a place. Such lesions are not artefacts due to the dropping out of bits of the tissue during or after the sectioning, since the pieces are embedded in celloidin and there is no evidence of such vacancies in the celloidin, which is itself faintly stained and would therefore show gaps.

FIG. 14.—Organ of Corti, with fourth degree injury, tangential section. Guinea pig 28, left cochlea, 1-2-7, junction of third and fourth half-turns 295×. Compare with Fig. 10, which is of this type of lesion in radial section. Comparison with Fig. 12 emphasizes how much destruction has occurred.

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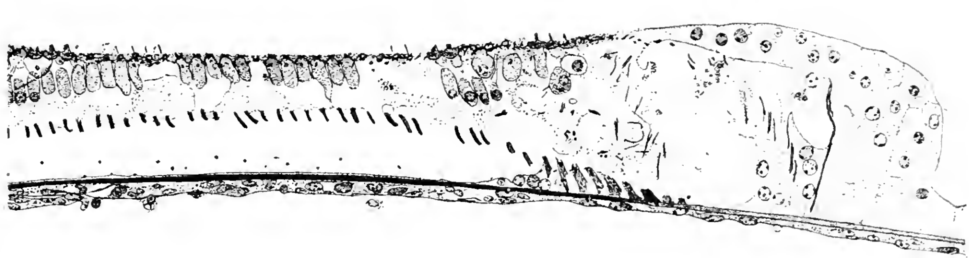

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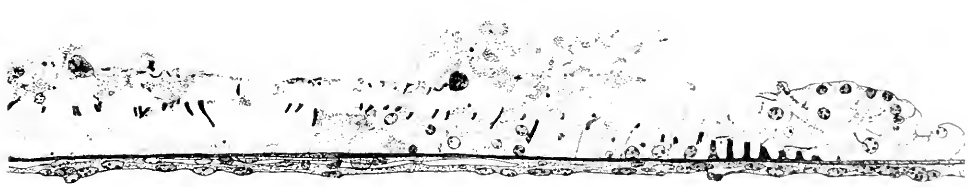

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Plate III.

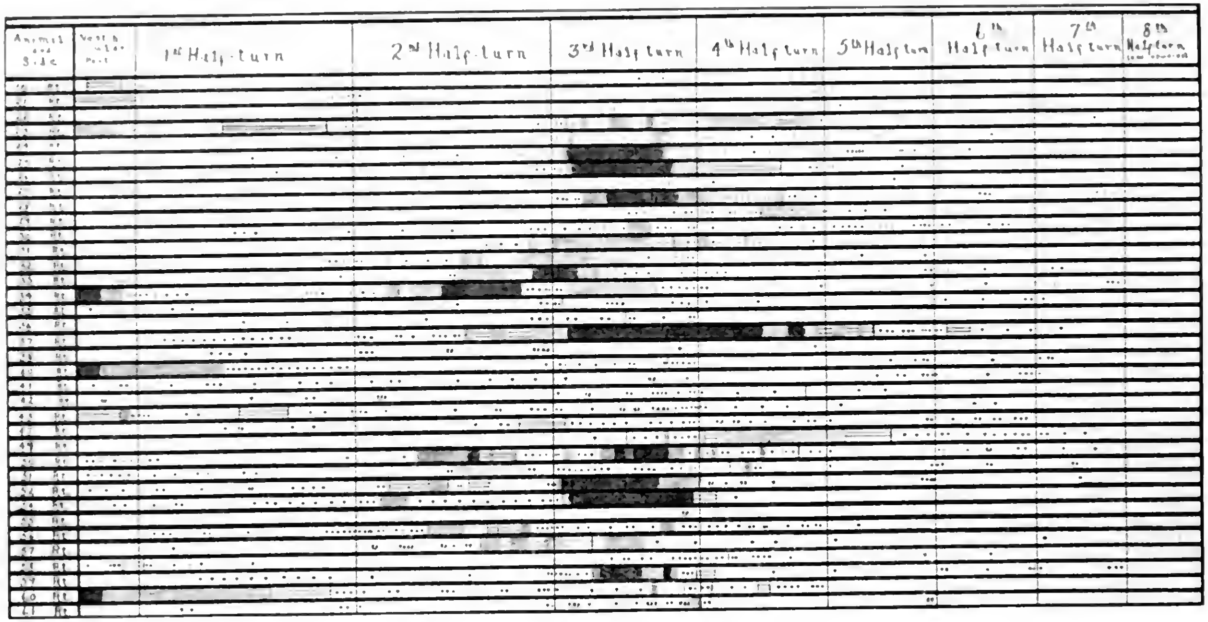


Chart I—Plate IV.

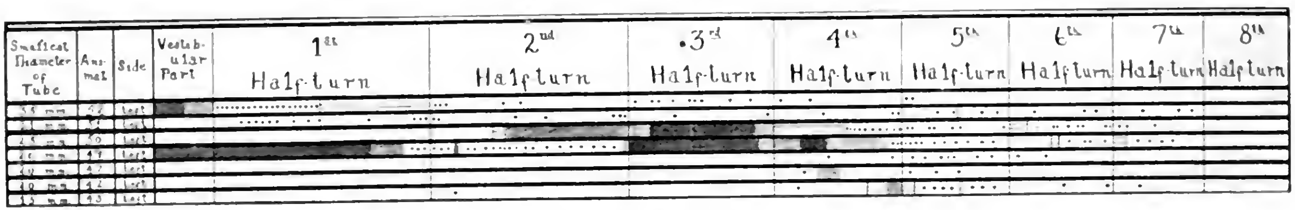


Chart II—Plate IV.

(For description of charts see page 28.)

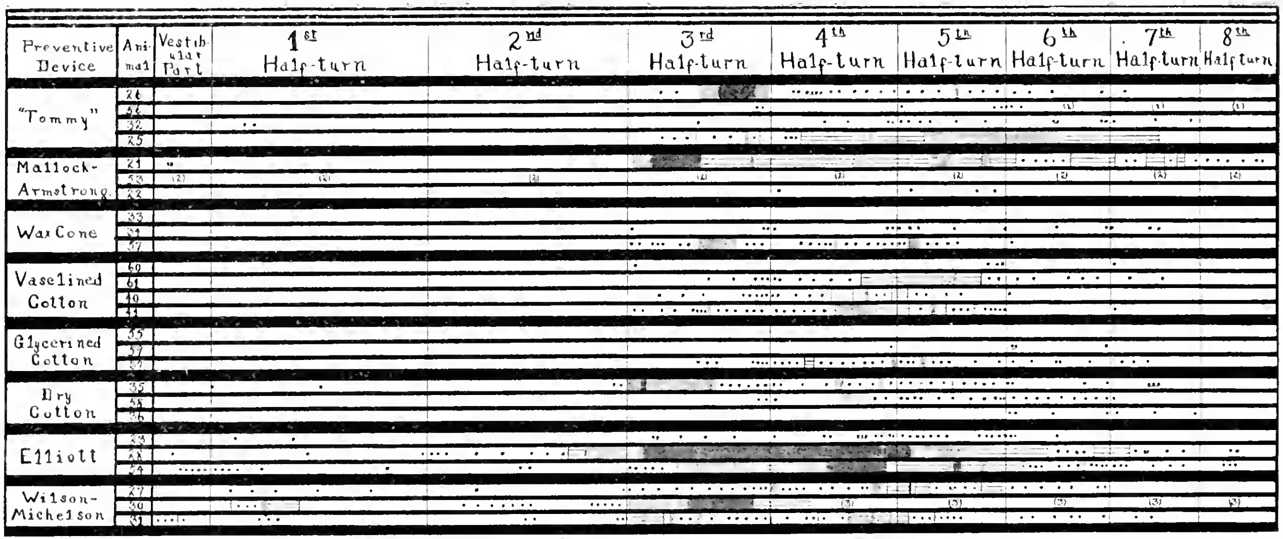


Chart III—Plate IV.

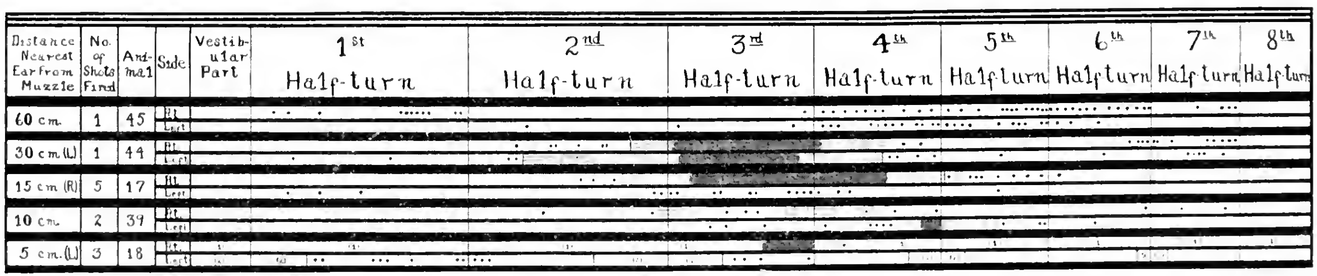


Chart IV—Plate IV.

(For description of charts see page 28.)

## Legend for Plate IV

*(See pages 26 and 27.)*

For the explanation of the general plan of the charts and of the symbols used, see the text matter, page 7, and the preceding description of lesions. The numbers in parentheses refer to the notes given in the legends for the individual charts.

CHART I.—A graphic presentation of the condition of the organ of Corti in the cochleæ of ears which were entirely open when exposed to the detonation produced by one shot from a 45 caliber Colt automatic pistol, fired with the muzzle at 15 cm., measured from the opposite ear, the barrel pointing downward about 20 degrees from the horizontal from above and in front of the animal along the left side.

CHART II.—A graphic presentation of the condition of the organ of Corti in the cochleæ of the ears which had the open rubber ear and a glass tube, of the dimensions given in the chart for each case, placed in the usual way. With the 2.0 mm. tube, examination of the wax packing after the shooting showed the presence of wax in the end of the tube with animals 47 and 42. (Cf. Table II of the middle ear report.)

CHART III.—A graphic presentation of the condition of the organ of Corti in the cochleæ of the ears which were protected by the methods indicated. These are left cochleæ in every case, and the position of the gun was that given in the legend for Chart I, except that the distance was measured from the protected ear.

(1) (Animal 56) The fixation of these turns is too poor for one to be certain as to possible injuries of limited extent, there are none of large extent.

(2) (Animal 53) The fixation is so poor that the sections are worthless for the determination of detonation injuries.

(3) (Animal 30) The apex of this cochlea was accidentally crushed during its removal; the resulting gross distortion is too great for one to be certain of the condition of the organ of Corti in these apical turns.

CHART IV.—A graphic presentation of the condition of the organ of Corti in the cochleæ of ears which were entirely open when exposed to detonations from a 45 caliber Colt automatic pistol with other than the usual arrangement (see legend to Chart I). The distance from the muzzle and the number of shots fired are indicated in the chart for each case. For the more exact position of the gun each time, reference may be made to Table I of the middle ear report.

(1) (Animal 18, right cochlea) The fixation is too poor for one to be certain of more than the general condition; there may be other areas of injury of small extent, but there are no other extensive injured zones.

(2) (Animal 18, left cochlea) This cochlea was not entirely sectioned because of poor decalcification; the areas blocked off are those not sectioned; their condition is accordingly unknown.

PUBLISHER'S NOTE.—The exact distribution of the fourth degree injury does not show clearly in these charts as printed, owing to the lack of differentiation of the intermediate and dark grays.